Evaluation of the Use of Compressive Growth Structure in Earthquake Hazard Assessment

14-08-0001G 1699

John Suppe, R.E. Bischke, J. Shaw

Department of Geological and Geophysical Sciences
Princeton University
Princeton, NJ 08540
(609) 258-4119

Investigations:

The object of this study is to characterize active crustal faults in the greater Los Angeles region that do not reach the surface, utilizing growth fault-propagation and growth fault-bend fold theory. Emphasis will be placed on determining slip rates on blind thrust faults in the transpressive environment of the Santa Barbara Channel.

Results:

Axial Surface or Dip Domain Mapping

We present a straightforward technique of analyzing three-dimensional structural geometry by mapping axial surfaces (Tearpock and Bischke, 1991) through a grid of 100 high resolution seismic reflection profiles located in the eastern Santa Barbara Channel, along the Blue Bottle and offshore Oak Ridge trends. Fundamental to the theories of fault-related folding (Suppe, 1983; Suppe and Medwedeff, 1990; Suppe et al., 1991) is the formation of folds in the upper crust by migration of material through active axial surfaces in response to slip on non-planar faults. The locations of these axial surfaces can often be readily interpreted from seismic reflection profiles (Figure 1). Axial surface maps are generated by projecting these surfaces to the horizontal datum of the reflection profiles, and plotting their locations on a map (Figure 3).

When plotting the axial surfaces on a map, distinctions can be made between active, inactive, and growth axial surfaces. Active axial surfaces, which are located at bends in fault surfaces, actively deform and bisect growth (syntectonic) and pre-growth strata. Inactive and growth axial surfaces are passively translated above faults, and either terminate at fault surfaces or are refracted into the syntectonic section. Furthermore, growth axial surfaces have the additional property in that growth sediments deposited early in the slip history of the underlying fault record a wider kink band width than do growth sediments deposited later (Figure 1). These narrowing upward kink bands, or growth triangles, have been recognized in the Santa Barbara Basin and in other areas of southern California and throughout the world (Suppe et al., 1991). Inactive growth axial surfaces do not bisect the angle between the beds due to thickness changes across the axial surface. These thickness changes record different sedimentation and/or fault slip rates. All of these axial surfaces record the amount of slip that has occurred during the formation of the structure, and thus if ages of syntectonic sediments are known, one can determine slip rates along the causative faults.

The pattern of the trends of the axial surfaces on the map provides direct information on the subsurface structure and slip history of the underlying fault(s). The spacing between inactive and active axial surfaces reflects the magnitude of slip on the underlying fault, and limb length and fault slip can be calculated in cases where limb dip and fault geometry can be constrained. In cases where fault geometry cannot be inferred, limb length provides a reasonable estimate of the fault slip (Suppe et al., 1991). Changes in horizontal spacing, (i.e. convergence or divergence), of axial surface pairs suggests a change in slip on the underlying fault along strike. Changes in axial surface trends may also reflect gradual changes in subsurface fault geometry, such as changes in fault step up angle. Dramatic differences in the limb length between different sets of axial surface pairs suggests that the structures grew by movement on different faults and/or at different times. In addition, terminations and offsets of axial surfaces help to identify subsurface fault tears (Tearpock and Bischke, 1991) (Figure 2).

Offshore Oak Ridge and Blue Bottle Trends

An axial surface map of the offshore Oak Ridge and Blue Bottle trends generated by this method is presented in Figure 3. The active axial surface which bounds the northern flank of the Oak Ridge trend (axial surface A, Figure 2 and 3), extends for over 38 km in the eastern Santa Barbara Channel, from due south of the city of Santa Barbara east to the onshore Ventura Basin. The inactive axial surface (A'), which bounds the southern flank of the fold parallels the active axial surface (A), along the northern front of the offshore Oxnard Plains. The limb length of the fold (L), which can be measured directly from the map, remains roughly constant at 11.5 km. This value represents a minimum estimate of the dip slip component of movement on a deep seated fault beneath the channel.

Deformed near surface sediments along the offshore Oak Ridge trend (Figure 1), indicate that this deep seated fault remains active. The great depth and the dip of this fault, represented in a balanced model in Figure 2A, suggests that it surfaces to the south of Santa Cruz Island. Since the beginning of the deposition of the Repetto mudstone (estimated at 3.3 m.y.), we calculate that this deep channel fault has slipped at a minimum average rate of 1.7 mm/year. Traces of selected axial surfaces of the shallower Blue Bottle fold, modeled in Figure 2B, are also reported on the map in Figure 3B. In general, the limb length of the fold and fault slip on the Blue Bottle thrust remains constant across the eastern channel. This structure is also presently active and a 1.6 mm/year can average slip rate for the Blue Bottle fold is calculated using an estimated early Pleistocene age of fold growth initiation and the maximum limb width on the north flank of the trend of 1.2 km (Figure 3B).

The combined 3.3 mm/year early Pleistocene to Recent fault slip rates calculated for the channel faults can account for only about one third of the predicted 10 mm/year of shortening along the plate margin directed normal to the San Andreas Fault (DeMets et al., 1987; and others). This 10 mm/year value represents the normal component of the vector which describes the discrepancy between the calculated Pacific-North American relative plate motion and estimates of slip rates on the San Andreas Fault. The remaining 6 or 7 mm/year of predicted crustal shortening normal to the San Andreas since the early Pleistocene represents the amount of shortening which must be accommodated by other structures in the western Transverse Ranges northeast of this transect. Present day convergence rates across the channel must be accounted for by movement on these and other faults beneath the Santa Barbara Channel and along the Santa Barbara coast.

References

DeMets, C., Gordon, R.G., Stein, S., and Argus, D.F., 1987. A revised estimate of Pacific-North America Motion and Implications for Western North America Plate Boundary Zone Tectonics, Geophysical Research Letters, Vol. 14, No. 9, p. 911-914.

Suppe, J. and Medwedeff, D.A., 1990. Geometry and kinematics of fault-propagation folding, Ecologae Geol. Helv., v. 83/3, p. 409-454.

Suppe, J., 1983. Geometry and kinematics of fault-bend folding, Am. J. Sci., v. 283, p. 684-721.

Suppe, J., Chou, G.T. and Hook, S.C., 1991. Rates of folding and faulting determined from growth strata, Thrust Tectonics, K.R. McKlay ed., Unwin Hyman, Publisher in press.

Tearpock D. and R. E. Bischke, 1991. Applied subsurface geological mapping. Prentice-Hall, N. J. 649 p.

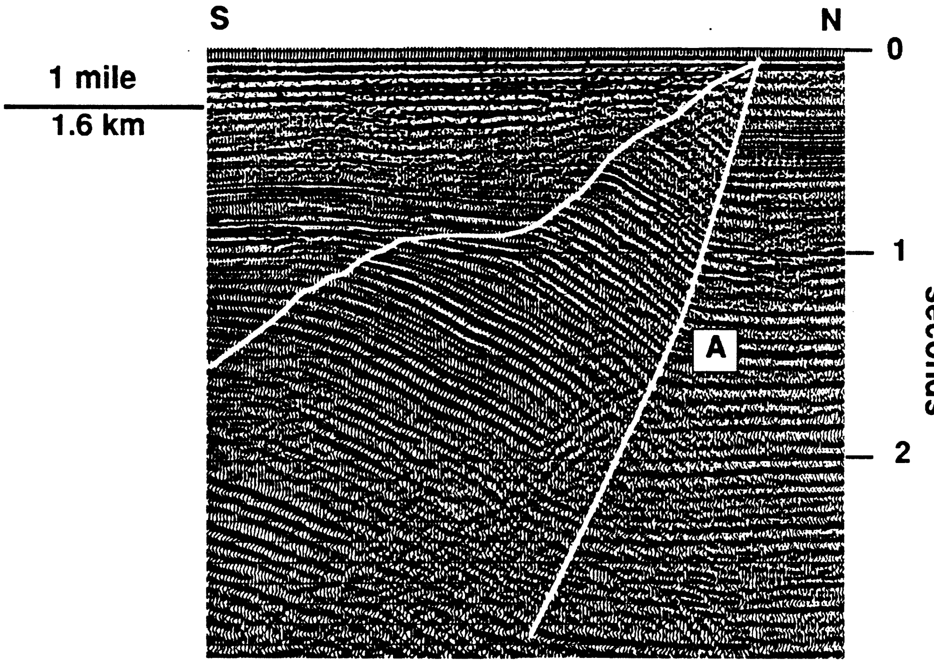

Figure 1: A migrated seismic reflection profile which images a narrowing upward kink band, or growth triangle, in the Santa Barbara Channel along the offshore Oak Ridge trend. (A) is an active axial surface mapped in Figure 3.

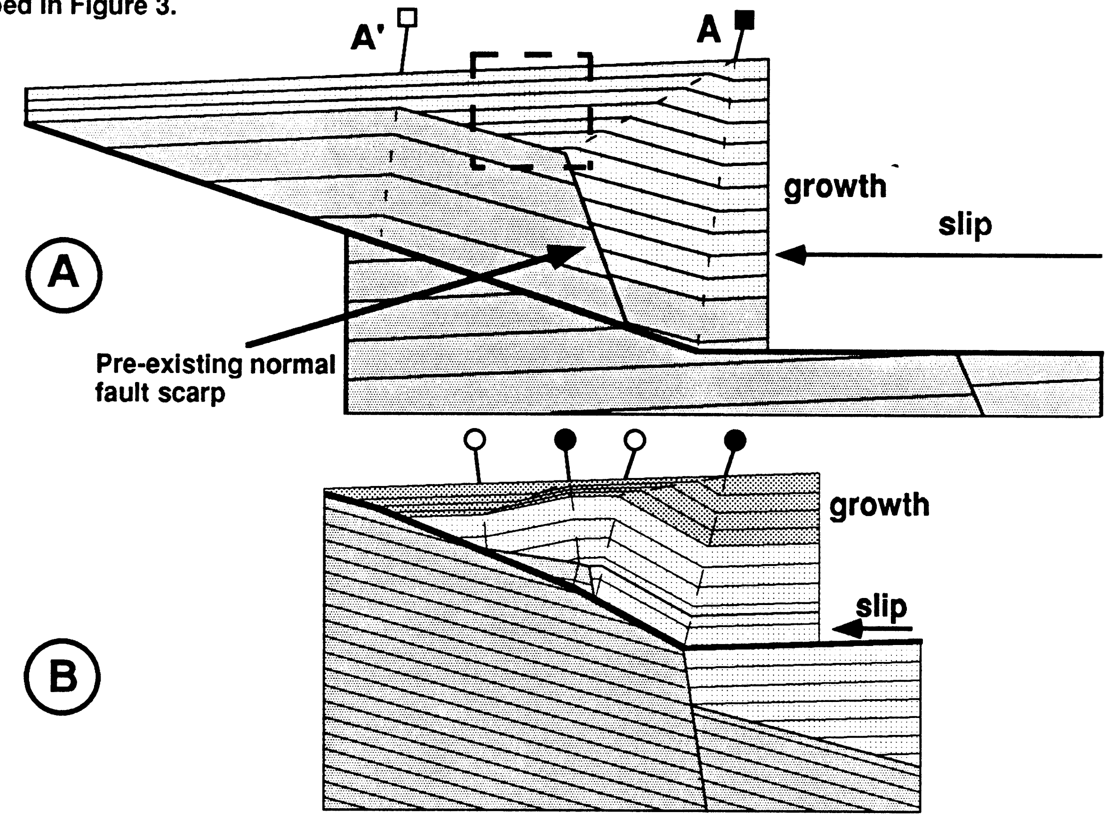

Figure 2A: A balanced model of the offshore Oak Ridge Trend. During the initial stages of slip on the thrust, sedimentation is confined to a rift basin opened during Miocene normal faulting. Only after the basin is filled and the normal fault passes through the active axial surface (A) does a narrowing upward kink band, or growth triangle, develop. The dashed box outlines the location of Figure 2B, which is a generalized model of a stage in the development of the Blue Bottle structure. Squares and circles mark axial surfaces mapped in Figure 3.

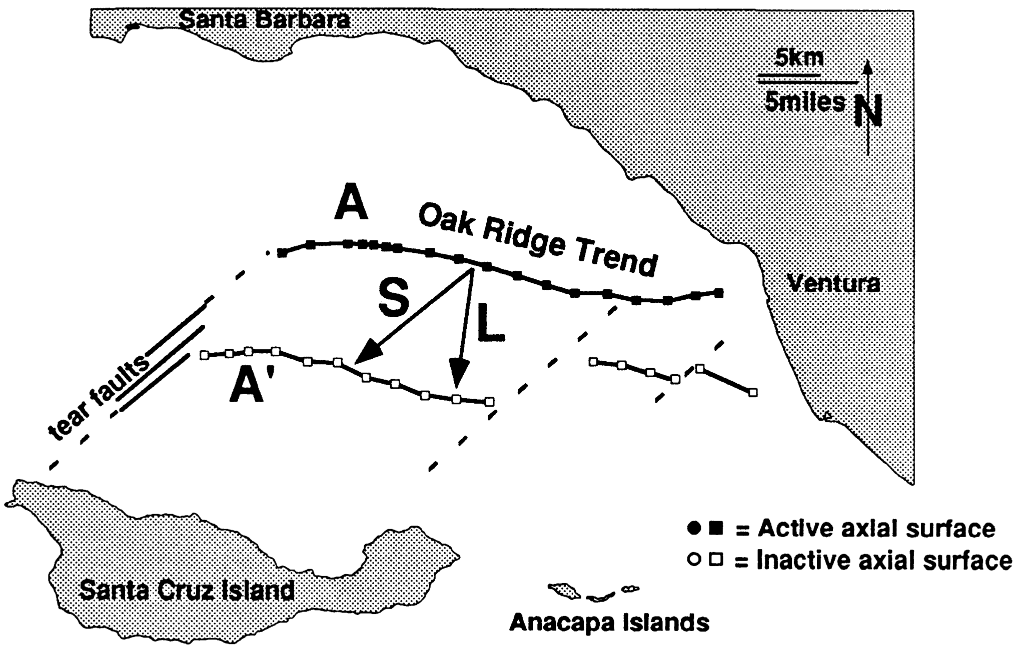

Figure 3A: A map of the active (A) and inactive (A') axial surfaces associated with the offshore Oak Ridge trend. In the west, the axial surfaces terminate into a series of left-stepping tear faults, and to the east offsets in axial surface (A') suggest other subsurface tears. The similar shapes of (A) and (A') and the orientations of the tear faults suggests oblique left-lateral reverse slip (S) on the underlying thrust directed NE to SW. (L) represents the limb length of the fold and the minimum amount of dip slip on the underlying thrust fault.

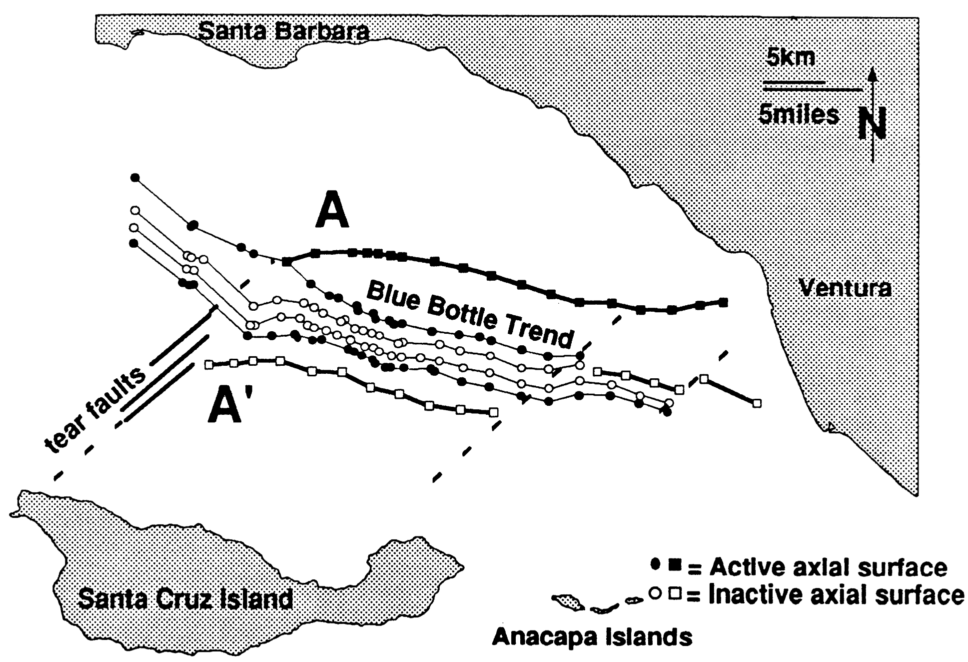

Figure 3B: A map of selected axial surfaces of the Blue Bottle trend. Constant spacing of the axial surfaces across most of the channel suggests that slip on the underlying thrust(s) remains roughly constant. In the west, the widening of the Blue Bottle trend is caused by folding of the structure by the underlying thrust associted with the offshore Oak Ridge Trend. In the east, the back or north limb of the Blue Bottle fold terminates into a tear fault which also offsets the Oak Ridge axial surface (A').